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A TECHNIQUE FOR INTERPRETATION OF MULTISPECTRAL REMOTE SENSOR DATA

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BIOGRAPHICAL SKETCH

Mr. Williamson was graduated from Millsaps College, Jackson, Mississippi, in 1956 with a B. S. degree in physics. In July 1963 Mr. Williamson joined the engineering staff of the Terrain Analyzer Section, Army Mobility Research Branch, Mobility and Environmental Division, U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi. He has supervised radar, infrared, and gamma-ray tests conducted to determine the capability of these regions of the electromagnetic spectrum to convey information related to soil trafficability conditions. In 1969 he was appointed Acting Chief, Remote Sensing Section, Terrain Analysis Branch, Mobility and Environmental Division, and in 1970 he was made a Senior Project Manager. He is currently managing projects directed toward applications of remote sensor data to problems of the Corps of Engineers. These include use of the ERTS-1 data to inventory the nation's reservoirs and other impounded water bodies, and to delineate the land area inundated by water during the spring flood in the Lower Mississippi Valley, and use of ERTS and other remote sensors to map the dispersion of sediment and pollution in the Chesapeake Bay area and Lake Pontchartrain.

ABSTRACT

The U. S. Army Engineer Waterways Experiment Station is engaged in a study to detect from ERTS-1 satellite data alterations to the absorption and scattering properties caused by movement of suspended particles and solutes in selected areas of the Chesapeake Bay and to correlate the data to determine the feasibility of delineating flow patterns, flushing action of the estuary, and sediment and pollutant dispersion. As a part of this study, ADP techniques have been developed that permit automatic interpretation of data from any multispectral remote sensor with computer systems which have limited memory capacity and computing speed. The multispectral remote sensor is considered as a reflectance spectrophotometer. The data which define the spectral reflectance characteristics of a scene are scanned pixel-by-pixel. Each pixel whose spectral reflectance matches a reference spectrum is identified, and the results are shown in a map that identifies the locations where spectrum matches were detected and spectrum that was matched.

This paper describes the interpretation technique and presents as an example interpreted data from the ERTS-1.

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INTRODUCTION

The utility of airborne and satellite-born remote sensor systems is steadily increasing. However, the use of new sensor systems, and attempts to extend the use of unconventional systems into conventional areas, has resulted in the emergence of a number of unexpected developments. For example, for years "standard" aerial photography consisted of prints or positive transparencies. With only a relatively limited amount of prior knowledge of a region, an experienced photo interpreter could identify landforms, cultural features, vegetation types, geological features, and so on. For a long time, conventional subjective interpretations of conventional aerial photos were adequate to meet the information requirement needs.

However, in recent years, requirements for far more subtle forms of information have emerged, and in response to these needs, remote sensing systems of far greater complexity have been built and flown. Consider, as an example, the multispectral scanner that is finding increasing acceptance among environmental researchers. This instrument takes up to 24 simultaneous pictures of each scene. Each picture in a group is a record of the spectral reflectances within a narrow band of wavelengths, and the entire group of photographs is a record of the spectral reflectances over the electromagnetic spectrum between approximately 0.3 and 13.0 micrometers. Each picture must be interpreted separately as well as with others in the group to extract information contained in the photography. Conventional interpretive techniques are inadequate because of the large number of photographs of each scene, the unfamiliar appearance of individual photographs in a group, and the inability of an interpreter to detect correlations among a group of photographs.

ANALYSIS TECHNIQUE

Engineers and scientists at the U. S. Army Engineer Waterways Experiment Station (WES) have developed an analysis technique that promises to alleviate some of these problems. Originally developed in connection with an Earth Resources Technology Satellite (ERTS-1) study of suspended particle and solute concentrations in the Chesapeake Bay area, the technique employs a small PDP-15 computer with an 8K memory. This computer has been found to afford considerably greater flexibility and versatility at less cost than a much larger computer also available at the WES. The computer algorithms that are used permit interpretations on the basis of all the pictures within a group and remove almost all subjectivity from the interpretation.

Concept

In the data analysis the multispectral remote sensor is thought of as a reflectance spectrophotometer that describes the spectral reflectance and/or emittance of a scene on a pixel-by-pixel* basis. As shown in

* A pixel (or picture element) is the smallest area of a scene over which radiant power is integrated for measurement.

fig. 1 each pixel on the ground has a corresponding pixel in each of the spectral bands of the multispectral sensor. By combining the values for a corresponding pixel in each spectral band, a reflectance spectrum for the corresponding area on the ground can be defined.

It is interesting to note that in this context the ability of the multispectral sensor to perceive small changes in spectral reflectance improves as the number of spectral bands received by the sensor increases. If the ERTS-1 multispectral scanner saw a body of water whose reflectance spectrum was as shown in fig. 2, the spectrum would be defined by only four values corresponding to the four bands (band 4-7) shown in fig. 2. On the other hand, 10 channels of the NASA 24-channel scanner would define the same spectrum in terms of a value for each of the bands shown. It is obvious that the spectrum is defined much more accurately by the 10 spectral bands obtained with the 24-channel scanner than by the four much broader bands obtained by the ERTS-1 multispectral scanner.

The computer program combines the data from each of the channels of the multispectral sensor to define the reflectance spectrum for each pixel, compares each spectrum with one or more reference spectra, determines the reference spectrum matched by each pixel, and at the same time retains the geometric relationship of each pixel comprising a scene so that the results of analysis can be shown on computer-generated maps. To accomplish these tasks, two inputs are required--the reference spectrum (or spectra) and a digital magnetic tape for each multispectral remote sensor channel in a format compatible with the computer program.

Determination of reference spectra

Reference spectra may be derived from one of three possible sources--prediction models, ground truth measurements, or ground truth coupled with remote sensor measurements. The exact procedure used to obtain reference spectra depends to a very large extent on the intended purpose of the multispectral remote sensor data acquisition. Therefore, the following discussion is very general in nature.

Prediction models suitable for defining the spectral characteristics of different objects or materials are being developed, but at this point are not developed to the extent that they can be used very extensively for remote sensor data interpretation. One such model being developed at the WES has been used to determine whether a specified film/filter combination can be used to detect a target whose spectral reflectance characteristics are known. In addition, the model computes the proper F-stop and shutter speed required to make the target appear on the film with a specified contrast ratio against its background or surroundings. This same model can be used to compute the spectral signature of a target as it would appear to a sensor at specified altitude and atmospheric conditions.

Another model being developed at Colorado State University by Dr. James A. Smith, et al, computes the apparent directional reflectance

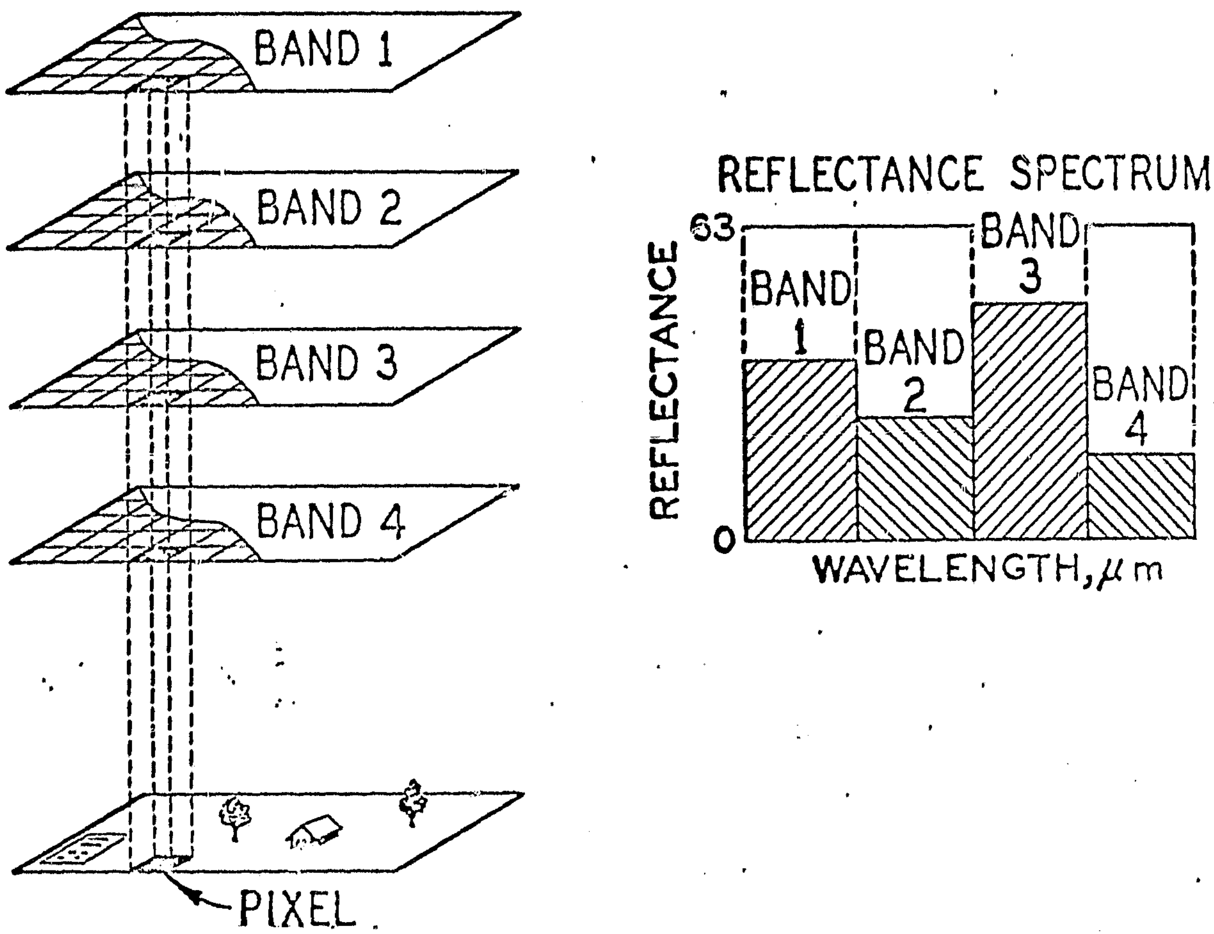


Fig. 1. Concept for Spectrally Describing a Scene

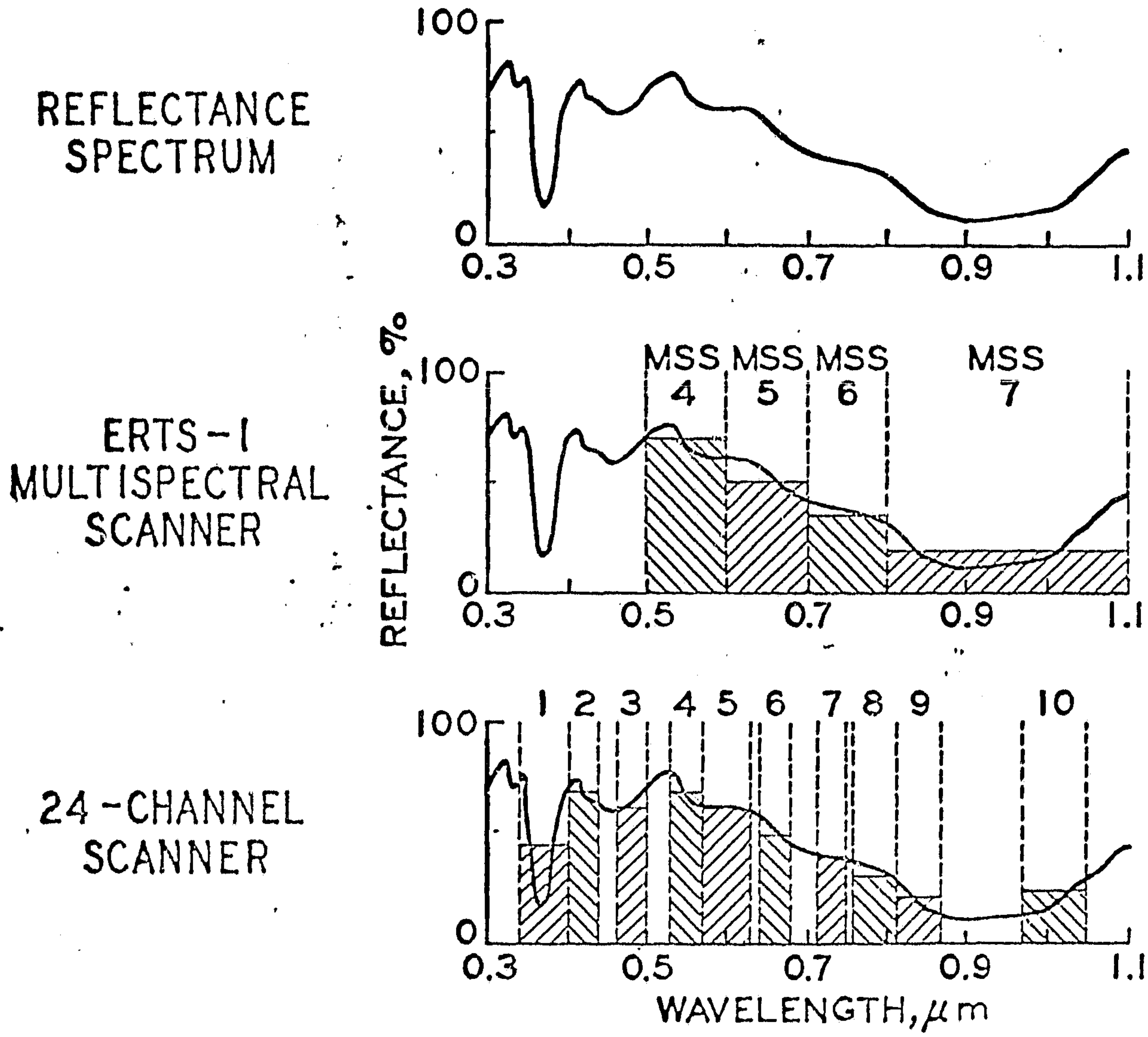


Fig. 2. Spectrum as Defined by Two Multispectral Remote Sensors

of vegetation, on the basis of solar angle and view angle, canopy geometry and optical properties, and soil background.

Reference spectra can also be derived directly from ground truth measurements of the spectral reflectance of objects or features of interest. Measurements can be made using any one of several relatively inexpensive instruments designed for this purpose. For best results the instrument should view a target through the same spectral bands as the multispectral remote sensor and measurements should be corrected for atmospheric effects. Measurements should be made within a time frame that includes multispectral remote sensor data acquisition.

An alternate approach used by the WES is to use ground truth data coupled with reflectance spectra for objects or features derived directly from the multispectral sensor data. Assume that the objects of interest are corn fields. After locating a "typical" corn field on the ground, the pixels in each data array that correspond to that corn field are located in computer printouts of the data arrays and the pixel values are combined to define the reflectance spectrum that will be used as the reference spectrum.

For compatibility with the computer program, all reference spectra must be segmented according to the wavelength bands viewed by the multispectral sensor and each segment defined by a value. For the PDP-15 at the WES the values must fall between 0 and 63.

Multispectral sensor data

Conventional multispectral sensors measure the spectral emittance and/or reflectance of a scene and define the results in the form of a set of photographs or electrical analogs recorded on magnetic tape. Such tapes are often used to generate photograph-like images of scenes by converting the electrical analog to light which is then used to expose a film.

The input to the computer program must be a set of digital magnetic tapes on which the spectral properties of a scene are defined by an orthogonal array of pixels for each spectral band. ERTS-1 and 24-channel scanner data are originally recorded digitally on compatible magnetic tapes which can be used for direct computer input. If the original remote sensor product is actually a photograph, the picture can be converted to the proper data form with a scanning microdensitometer that measures the optical density over the area of a film on a pixel-by-pixel basis with pixel sizes as small as 12.5 micrometers, converts the measured values to digital form, and records the results on computer compatible magnetic tape. With some degree of accuracy, the optical density values can be related to radiance or emittance if a calibration step wedge is included in the photograph. The geometric relationship of the individial pixels comprising the digitized scenes is retained so that scenes may be reconstructed in the form of a number array, or alternatively, an image (that is, a picture).

Data conversion

Regardless of the multispectral sensor or the scanning microdensitometer used, the data must be converted to a form that is compatible with the computer programs used. This step is necessitated by the desirability of processing the data on the PDP-15 computer. Data tapes are therefore re-recorded one data array per tape. Each pixel value is scaled to a number between 0 and 63 and is recorded on the new tapes (input tapes) as a 12-bit word. In this manner the six most significant bits in each word are allowed to remain free for use in identifying spectrum matches.

Spectrum matching

Figure 3 shows a flow diagram of the spectrum matching technique. The data on the tapes are depicted as an orthogonal array of pixels for each sensor band. Each input tape is checked pixel-by-pixel and the value of each pixel is compared with the value of the segment of the reference spectrum that corresponds to the tape being checked. In this process, a new tape (key tape) is recorded for each band. When a pixel value matches the corresponding reference spectrum value, a flag is recorded on the key tape along with the pixel value. The flag is recorded in one or more of the most significant bits of the 12-bit word containing the pixel value. The black pixels shown in fig. 3 denote the occurrence of a spectrum match.

The key tapes are then combined to produce an output which contains only keys and no pixel values. A key is recorded on the output tape only if a pixel in the key tape for band 1 and the corresponding pixel in the key tapes for each of the other bands has a key indicating a spectrum match. Thus, in fig. 4, since pixel 1a in band 1,2,3 and 4 has a key, a key is recorded in position 1a on the output tape. On the other hand, even though pixel 1d is keyed on the tape for band 1 and 3, no key is recorded for position 1d on the output tape because there is no key recorded in position 1d of the tape for band 2 and 4.

Data on the output tapes are suitable for producing maps that show the locations where spectrum matches have occurred, in the form of selected alpha-numeric characters or other symbols, or photomaps that show matches as selected shades of gray.

APPLICATION OF ANALYSIS TECHNIQUE

As an example of an application of the analysis technique described above, consider analysis that was done on an ERTS-1 scene of the Chesapeake Bay area. The purpose of the analysis was to detect from the ERTS-1 data alterations to the optical properties of water caused by suspended particles and solutes. The results were to be printed as maps that would be useful for studying flow patterns, flushing actions, and sediment and pollutant dispersions.

Four bands of the ERTS-1 multispectral scanner, MSS 4 (0.5 to 0.6), MSS 5 (0.6 to 0.7), MSS 6 (0.7 to 0.8), and MSS 7 (0.8 to 1.1 micrometers), were used in the analysis.

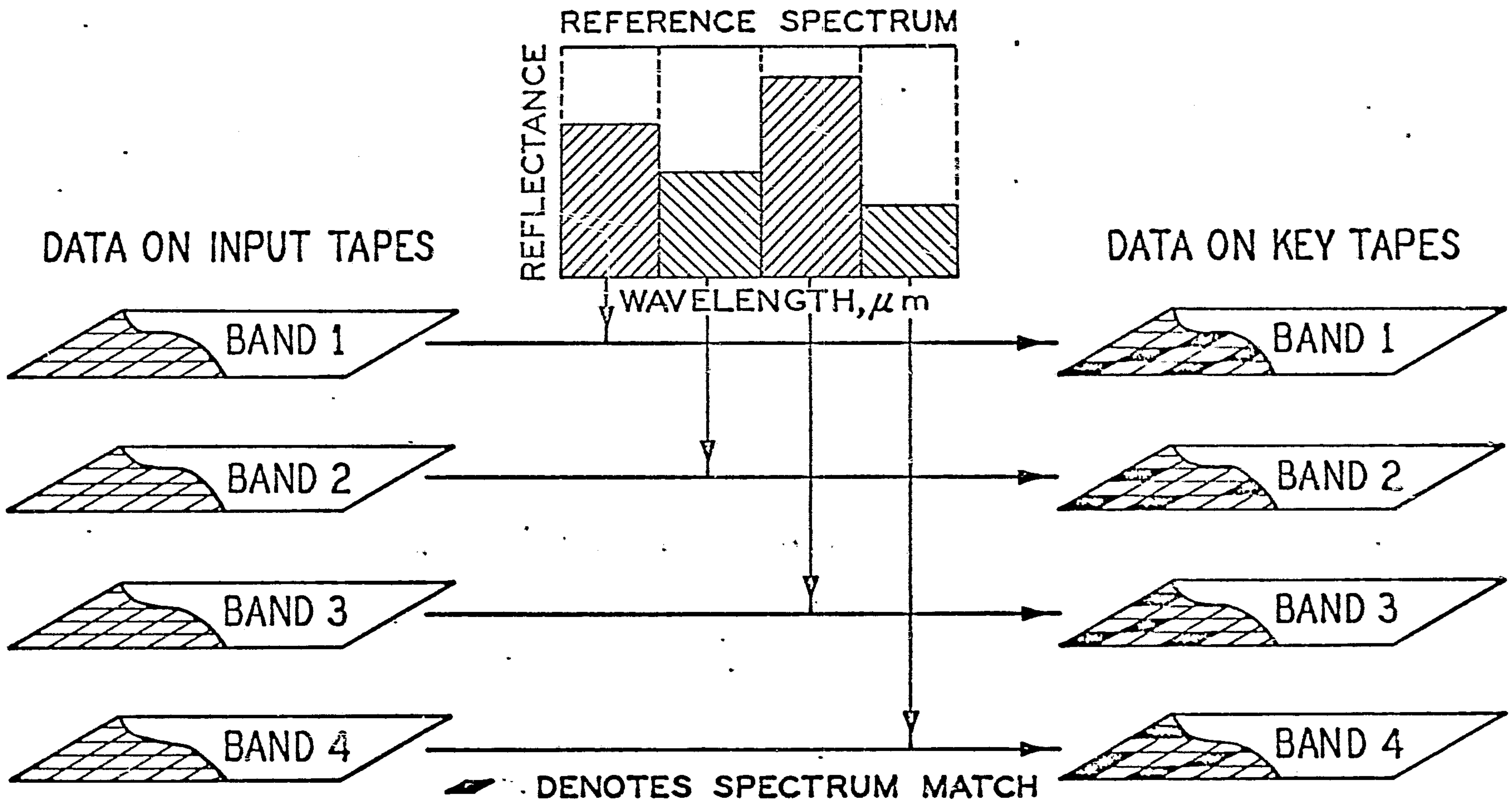


Fig. 3. Technique for Spectrum Matching

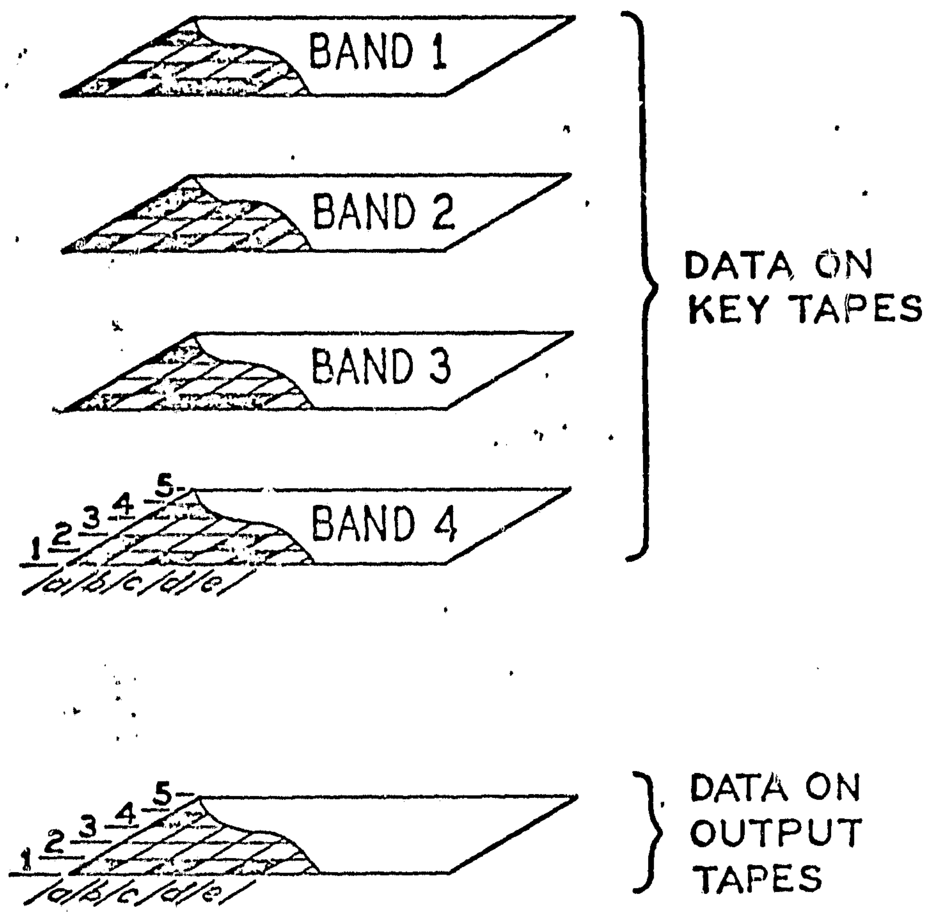


Fig. 4. Key Tapes Combined to Make an Output Tape

Determination of reference spectra

MSS band 7 values measured over water bodies were found to be very low, normally less than 0.20 mw/cm^2 -SR, due to the low reflectance of water in the 0.8- to 1.1-micrometer band; and the values contrasted sharply with those measured over land areas. This band therefore provided a convenient way to digitally mask or identify values corresponding to land areas in band 4, 5, and 6 data where land-water separations were not always clearly defined. MSS band 7 data were scanned on a pixel-by-pixel basis; and in each case where the value exceeded 0.20 mw/cm^2 -SR a binary "1" was placed in the first bit position of the 12-bit word containing the pixel value. The tape of MSS band 7 data then became a "mask" for printing out data for the other MSS bands.

Radiance values for MSS bands 4, 5, and 6 were each printed out using the band 7 mask to inhibit printing of values measured over land. Values for each band corresponding to a ground data collection station were located and were extracted from the printouts to define the reference spectra.

Fig. 5 shows a portion of a printout for MSS band 4 wherein the digital mask was used to eliminate values measured over land. Each printed value (in mw/cm^2-SR x .01) corresponds to a measurement over water. The number in the box is located at a position in the record that corresponds to a ground truth data collection station. At this point, the suspended material concentration was determined from the ground truth data to be 6.5 mg/l. The reflectance spectrum for this point is shown in the inset. The blank area in the lower portion of the printout corresponds to a land area--Grey Point on the Rappahannock River.

Correlations of reflectance spectra derived from the ERTS data and suspended material concentrations measured at ground data collection stations in the Rappahannock River on 10 October 1972 showed that the reflectance spectra were related to concentrations of suspended material in the following manner:

Suspended Material			Radiance, mw/cm^2-SR MSS Band		
Class	Map Symbol	Concentration (mg/l)	4	5	6
1	-	0-10	1.02-1.31	0.38-0.55	0.08-0.28
2	+	10-20*	1.36-1.48	0.46-0.71	0.16-0.32
3	*	20-30*	1.48-1.59	0.76-0.84	0.28-0.32
4	#	>30*	1.48-1.59	0.76-0.84	0.36-0.41

*Estimated concentration ranges

Ground truth data were collected at 19 points in the Rappahannock River. Water samples collected at 14 of these points contained less than 10 mg/l of suspended material, water from 3 points contained between 10 and 20 mg/l of material, and water from the remaining 2 points contained between

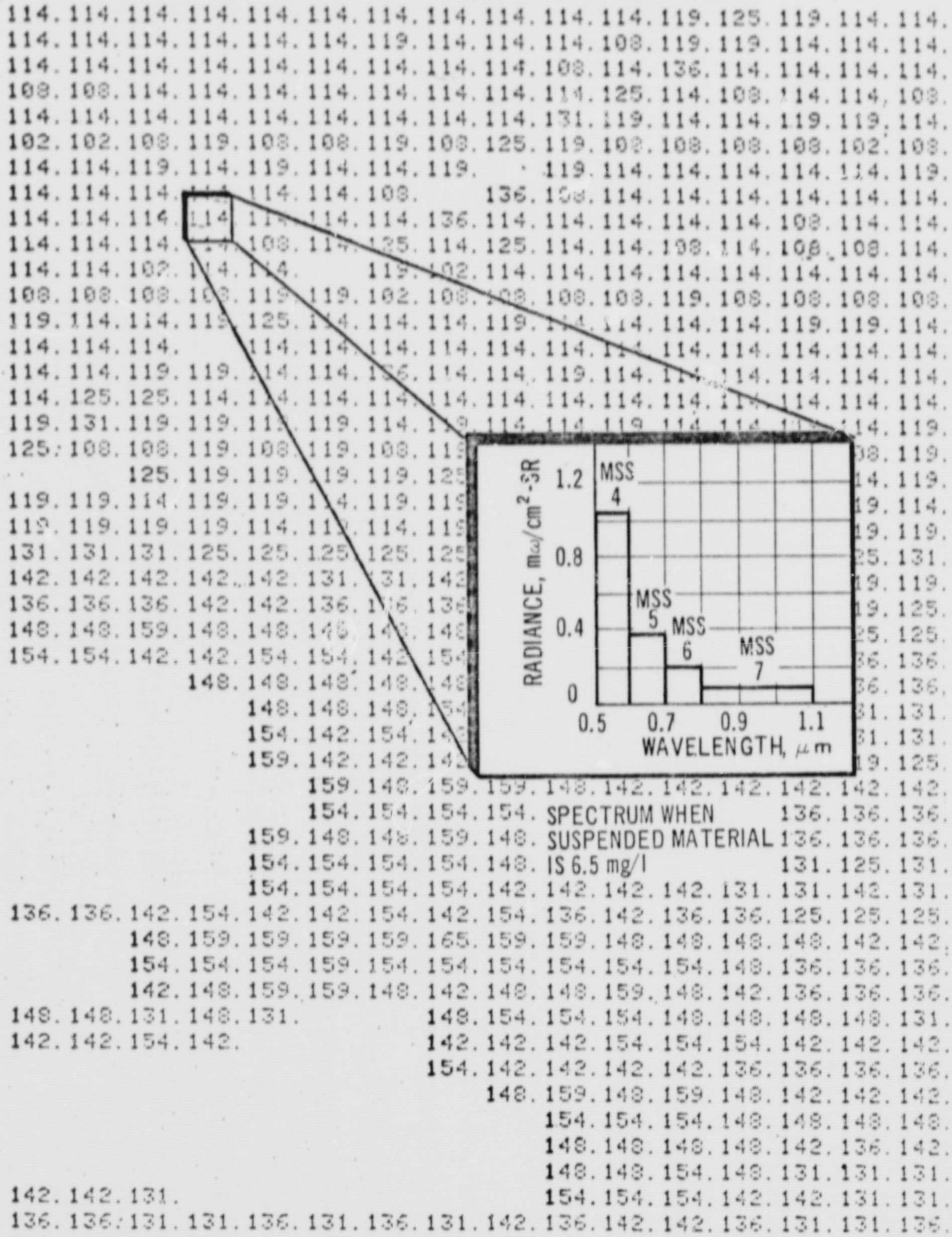


Fig. 5. Portion of Computer Printout of Data for MSS Band 4

20 and 30 mg/1 of material. Thus, the concentration ranges for class 2 and 3 are estimates based on a very limited amount of data. Likewise, the lower limit of class 4 could only be estimated.

The use of bands of radiance values to define a class as shown in the above table was necessary in order to account for variations in radiance values ($\pm$ 2 percent of full scale) introduced by the ERTS multispectral scanner.

Spectrum matching and results of computer analysis

Through use of ADP techniques, radiance values for MSS bands 4, 5, and 6 were scanned on a pixel-by-pixel basis and spectrum matches were identified according to the range in which the values fall. If the radiance value for a pixel in MSS band 4 and the corresponding pixel value for MSS band 5 and MSS band 6 all sorted into ranges according to one of the classes designated above, that pixel was re-identified by one of the map symbols shown in the table above. For example, the reflectance spectrum for the point designated by the box in fig. 6 has values as follows:

MSS band 4 = 1.36 mw/cm^2-SR
MSS band 5 = 0.46 mw/cm^2-SR
MSS band 6 = 0.24 mw/cm^2-SR

All the values fall within the ranges designated for class 2 in the table, and the pixel at that location is therefore identified by the symbol "+." A "0" in fig. 6 denotes pixel locations whose reflectance spectrum did not match a reference reflectance spectrum.

A computer-generated "map" such as the one shown in part on fig. 6 provides very high resolution but its large physical size makes it very impractical to use. However, this problem may be solved by writing the results of computer analysis on photographic film in terms of shades of gray (optical densities). Fig. 7 shows a photomap derived from computer analysis of ERTS-1 data of the York River. From ground truth data it was found that the concentrations of suspended material varied between 7 and 28 mg/1. Three spectra related directly to suspended material concentration were derived from the ERTS-1 data. The locations of the spectrum corresponding to the least concentration of material (0 to 16 mg/1) were denoted on film by an optical density of 1.68; the greatest concentration (>25 mg/1) by an optical density of 0.49, and an intermediate concentration (16 to 25 mg/1) by an optical density of 1.08. Pixel locations corresponding to land areas were not exposed (optical density = 0) and pixel locations where no spectrum was matched were denoted by writing maximum density (3.0). Fig. 7 is a print made from a negative written as described above.

CONCLUSIONS

The WES has developed a technique that considers a multispectral remote sensor as a reflectance spectrophotometer. ADP techniques requiring only limited computer capability are utilized to search the data

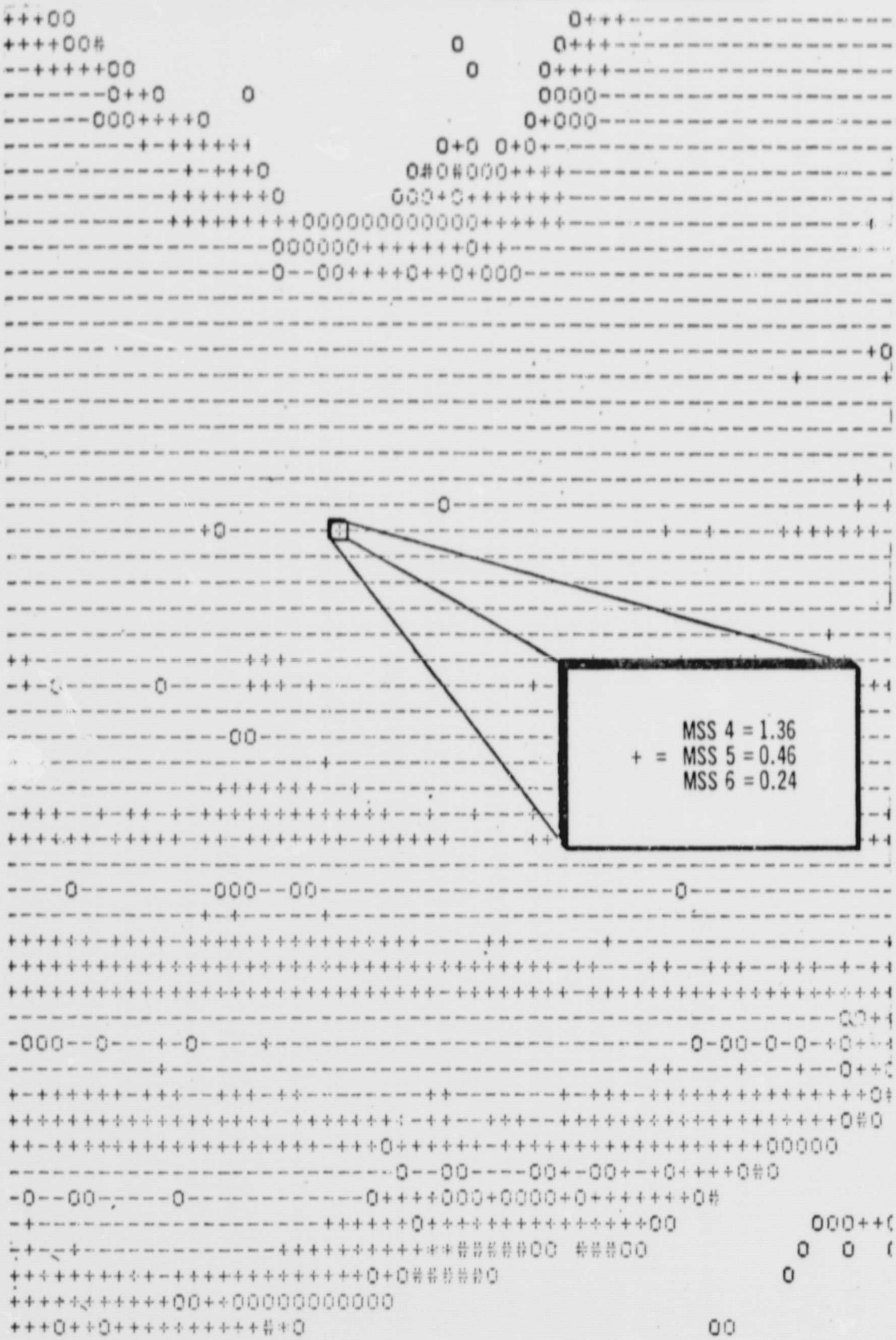
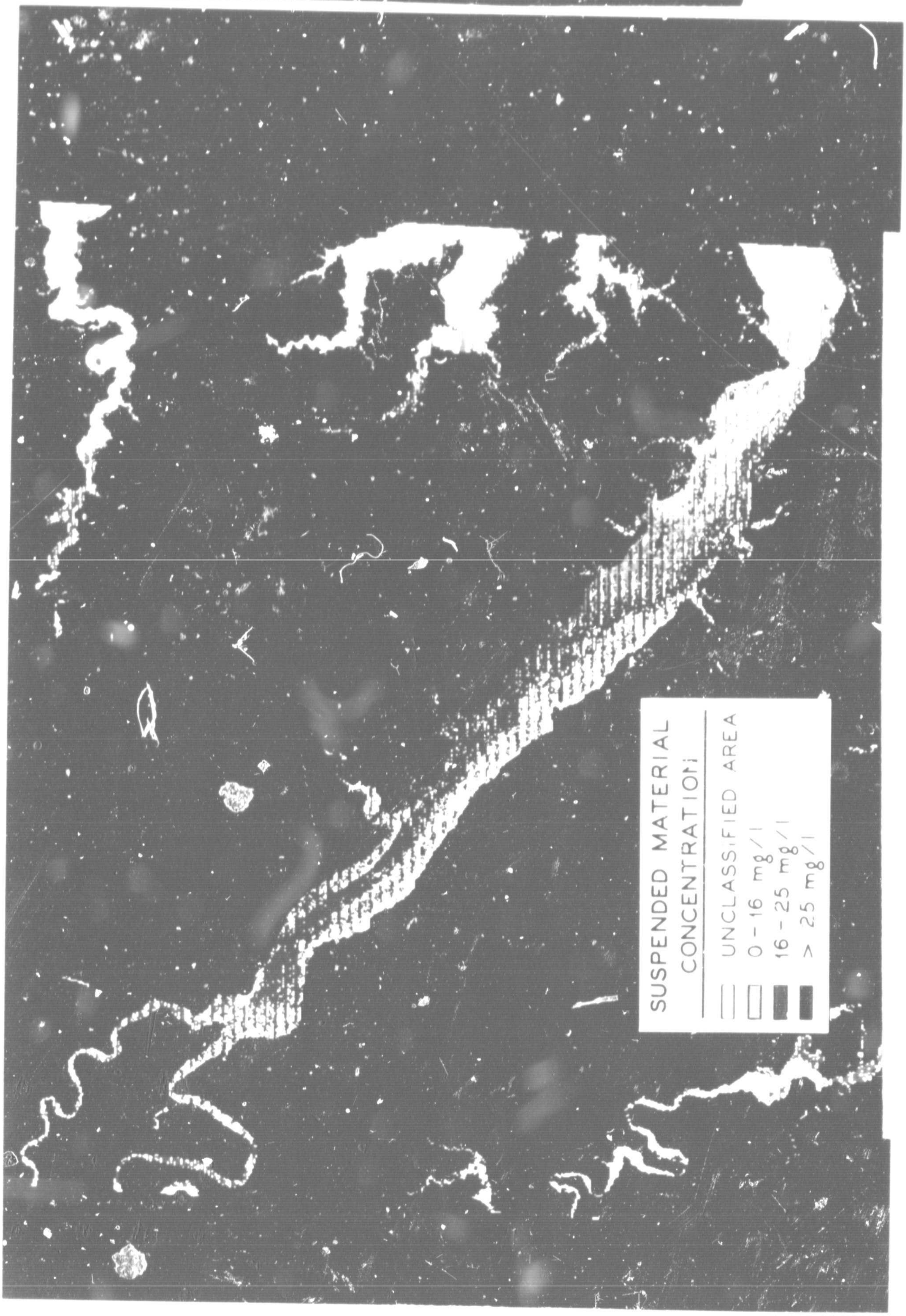


Fig. 6. Computer Generated "Map"


SUSPENDED MATERIAL
CONCENTRATION
UNCLASSIFIED AREA
0 - 16 mg/l
16 - 25 mg/l
> 25 mg/l

defining the spectral reflectance characteristics of a scene on a pixel-by-pixel basis, identify each pixel whose spectral reflectance matches a reference spectrum, and generate maps that identify pixel locations where spectrum matches occur and identify the spectrum that was matched.

The techniques described in this paper are currently being successfully used in connection with U. S. Army Corps of Engineers' projects to map the land area inundated by the 1973 spring flood in the Lower Mississippi River Valley, map sediment distributions in Lake Pontchartrain (in Louisiana) as a result of opening the Bonnet Carre Floodway during the spring flood, and inventory lakes and reservoirs in the states of North Carolina, South Carolina, Georgia, Florida, Alabama, Mississippi, Louisiana, West Virginia, and Kansas in connection with the National Dam Safety Program.